CS15210: Data Transmission

Helen Miles (hem23@aber.ac.uk)

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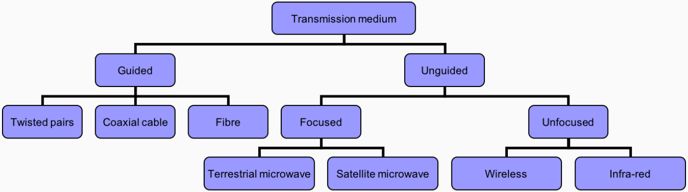
(based on slides by Mike Clarke)

Previously, in CS15210...

- Transmission media categories



- The overall factors affecting choice of medium:
  - cost, capacity, robustness, security
- The properties of each type of medium

Contents

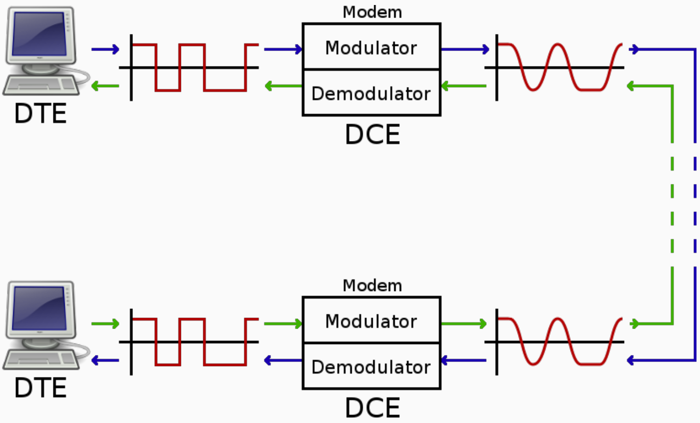
DTEs and DCEs

- DTE: Data Terminal Equipment
  - any device that is the source or destination of **digital** data
  - e.g. programs generating data, network cards
- DCE: Data Circuit-Terminating Equipment
  - any device that transmits or receives data in the form of an **analogue** or **digital** signal over a communications channel
  - e.g. modems

Modems

- Modem: **mo**dulator-**dem**odulator
- Modems convert signals for transmission across a communication channel:
  - **Modulation**: from digital to analogue
  - **Demodulation**: from analogue to digital
  - Must agree on a method beforehand

Modems



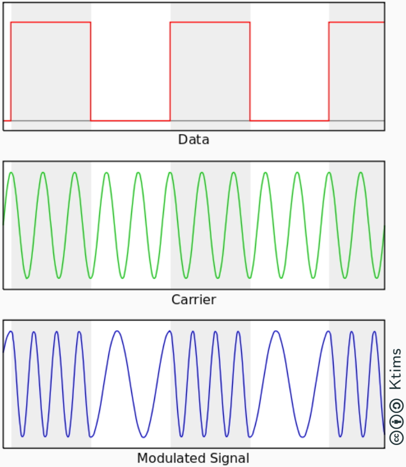
Modulation: from digital to analogue
Demodulation: from analogue to digital

Why convert between analogue and digital?

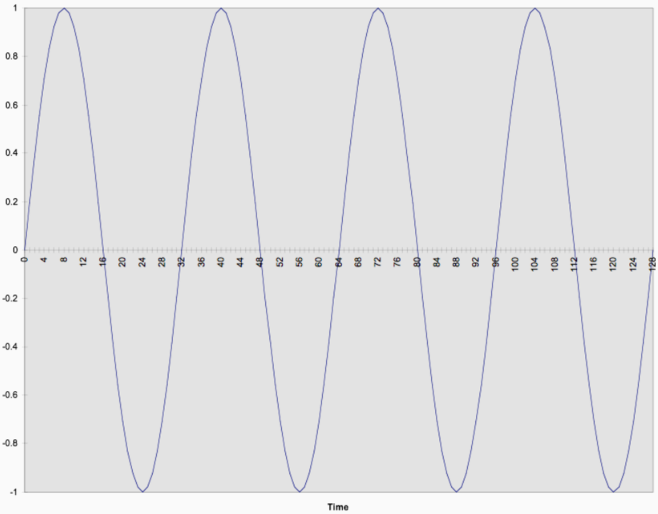
If a digital signal is sent down a wire just as it is,
it is very prone to distortion

Modulation and Demodulation

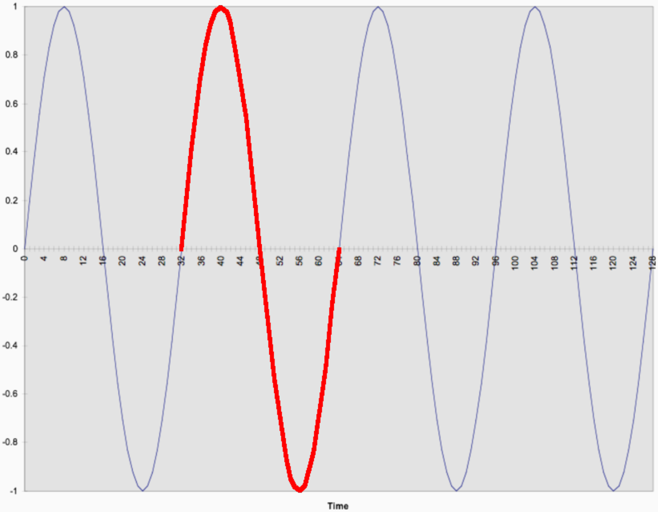
To avoid these problems,
the digital signal is used to change (modulate) a carrier wave



Waves: A Quick Recap



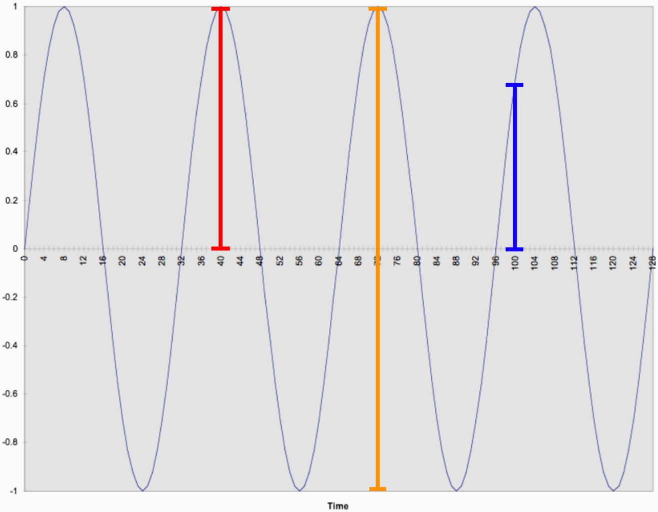
Waves: Frequency



Number of complete cycles per second, measured in Hertz (Hz)

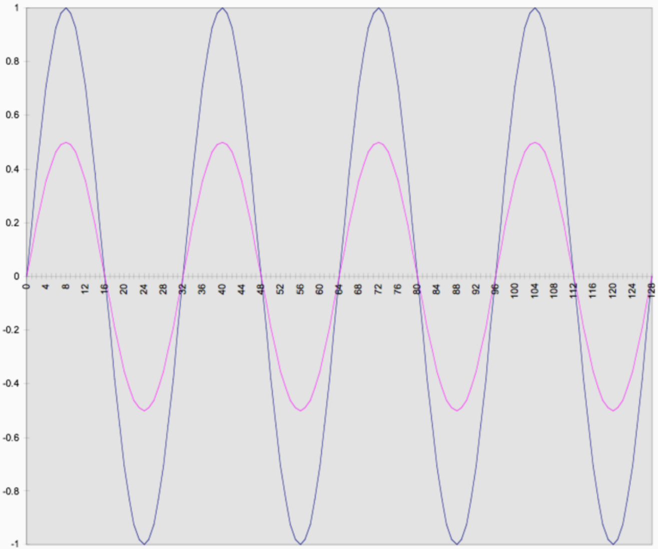
i.e. if a cycle takes 1 second, frequency = 1 Hz

Waves: Amplitude



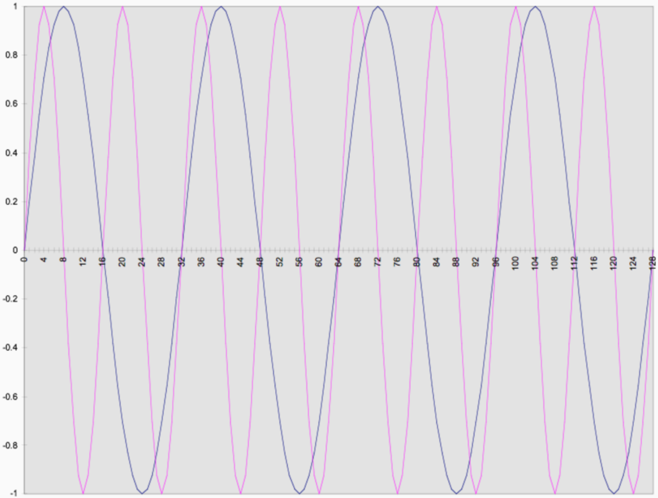
(Peak) amplitude, peak-to-peak amplitude, instantaneous amplitude

Amplitude Difference



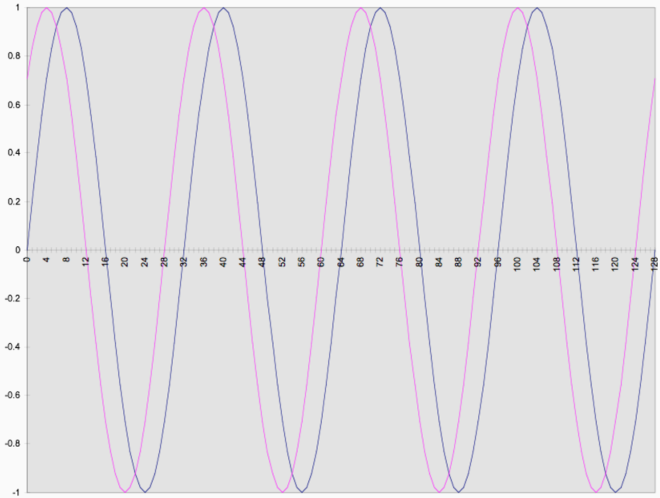
Two waves, the only difference is the amplitude

Frequency Difference



Two waves, the only difference is the frequency

Phase Difference

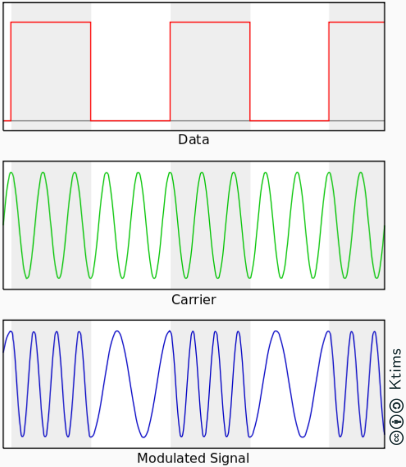


Two waves, the only difference is the start time of the cycle

Modulation and Demodulation

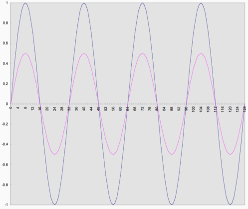
To avoid these problems,

the digital signal is used to change (modulate) a carrier wave

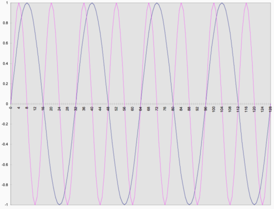


Types of Modulation

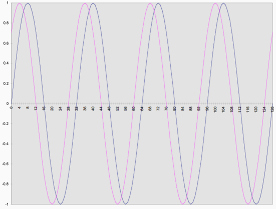
We can adjust the carrier wave to suit the type of data



Amplitude



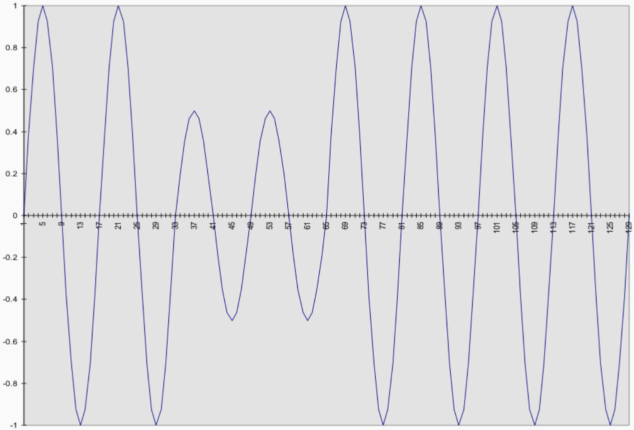
Frequency



Phase

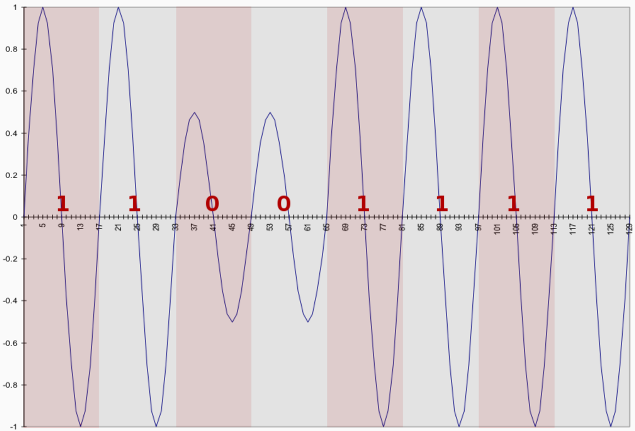
Analogue Data	Digital Data
Amplitude Modulation (AM)	Amplitude-Shift Keying (ASK)
Frequency Modulation (FM)	Frequency-Shift Keying (FSK)
Phase Modulation (PM)	Phase-Shift Keying (PSK)

Amplitude (ASK)



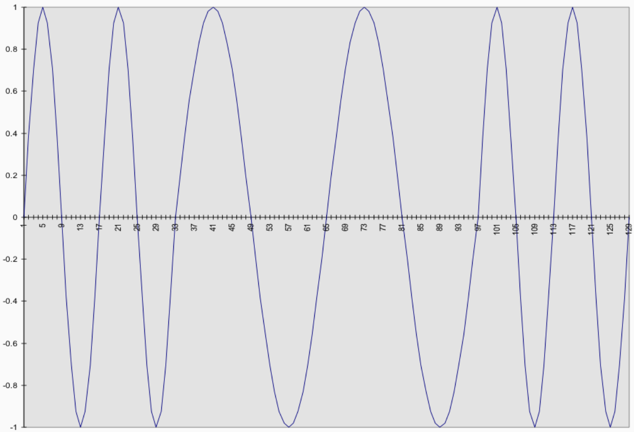
The carrier wave's **amplitude** is changed based on the digital signal

Amplitude (ASK)



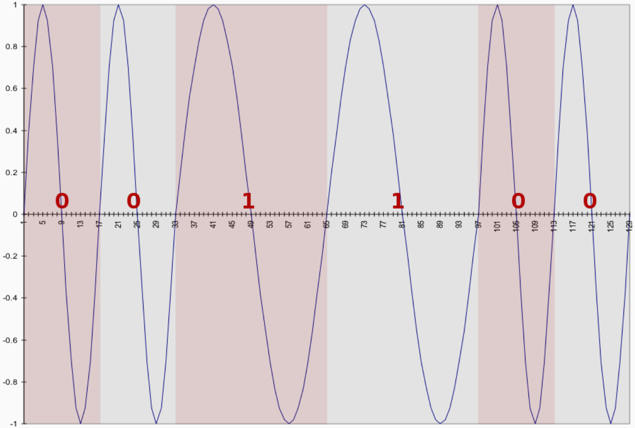
The carrier wave's **amplitude** is changed based on the digital signal

Frequency (FSK)



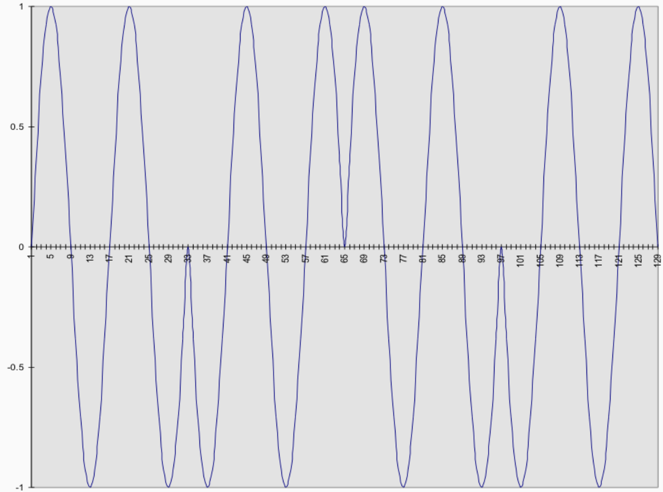
The carrier wave's **frequency** is changed based on the digital signal

Frequency (FSK)



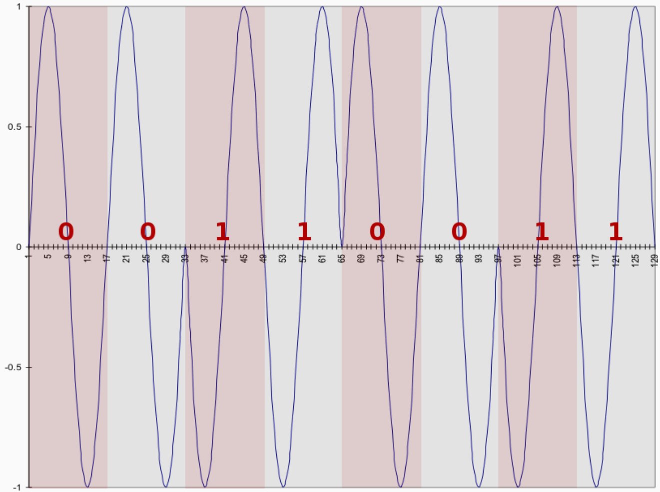
The carrier wave's **frequency** is changed based on the digital signal

Phase (PSK)



The carrier wave's **phase** is changed based on the digital signal

Phase (PSK)



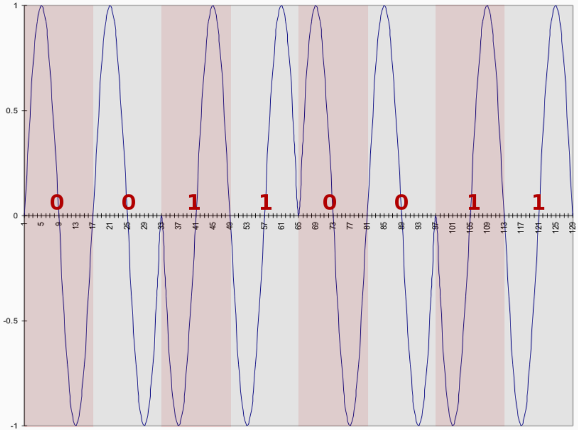
The carrier wave's **phase** is changed based on the digital signal

Properties: ASK, FSK, and PSK

- Some important things to note...
- ASK is much more susceptible to noise than FSK or PSK
  - noise usually affects amplitude more than frequency or phase
- FSK needs to use two frequencies
  - requires more bandwidth than ASK or PSK for same amount of data
- PSK can carry more information than ASK or FSK...

Phase (PSK)

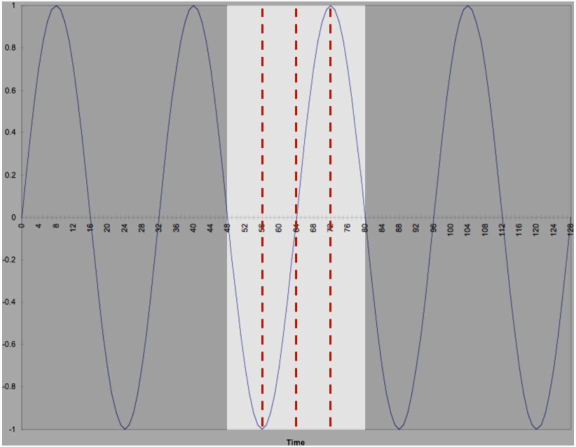
PSK can be used to represent data in two ways,



the first is to use the basic phase change
to signal the change in value

Phase (PSK)

PSK can be used to represent data in two ways,

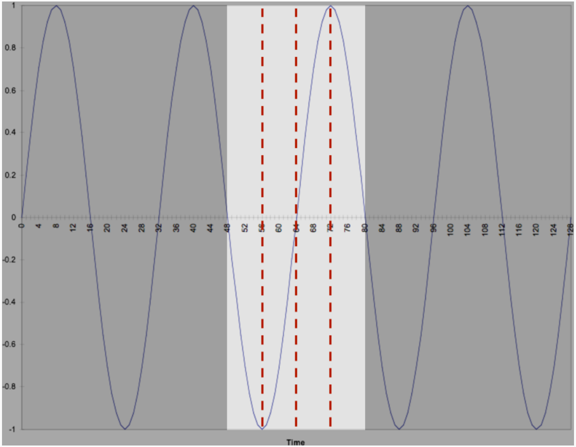


the second is to use the amount of shift

to signal the change in value

Phase (PSK)

Here, for example, if we split the wave into quarters



we can have four values derived from how much we shifted it

Phase (PSK)

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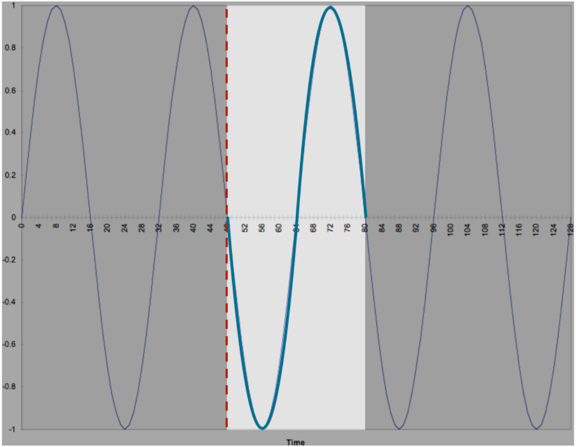

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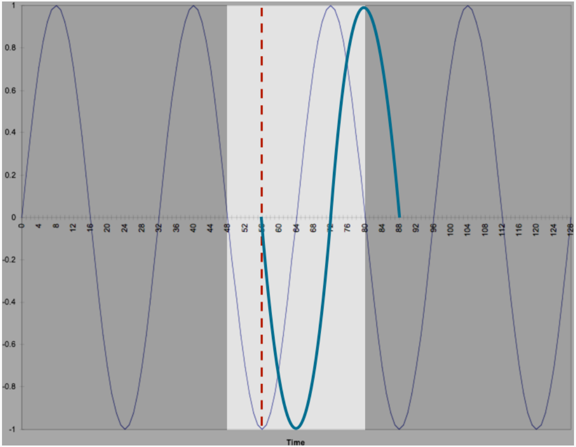

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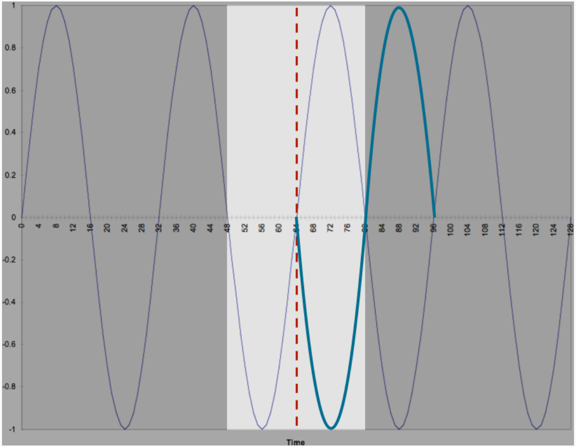

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Phase (PSK)

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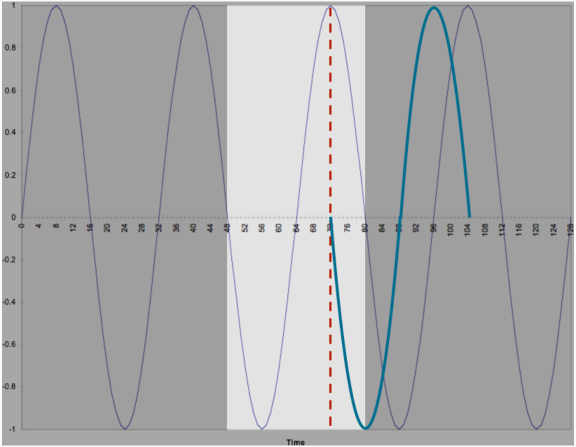
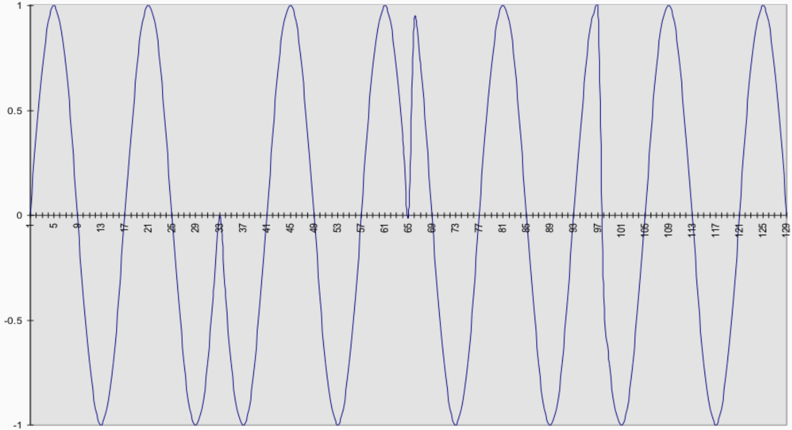


we can have four values derived from how much we shifted it

4-PSK

This is known as 4-PSK (or Quadrature PSK, QPSK)

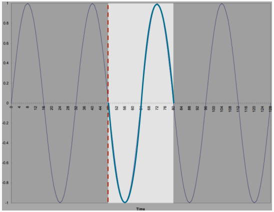


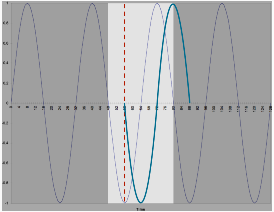
There is also 8-PSK, 16-PSK, etc.

4-PSK

There are four possible signal events,
so they can be used to represent two bits:

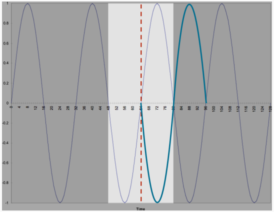
00

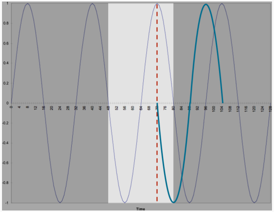




01

10





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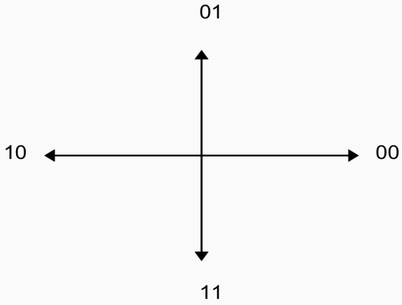
4-PSK

There are four possible signal events,
so they can be used to represent two bits:

00	0°	no change
01	90°	1/4 shift
10	180°	1/2 shift
11	270°	3/4 shift

4-PSK Constellation Diagram

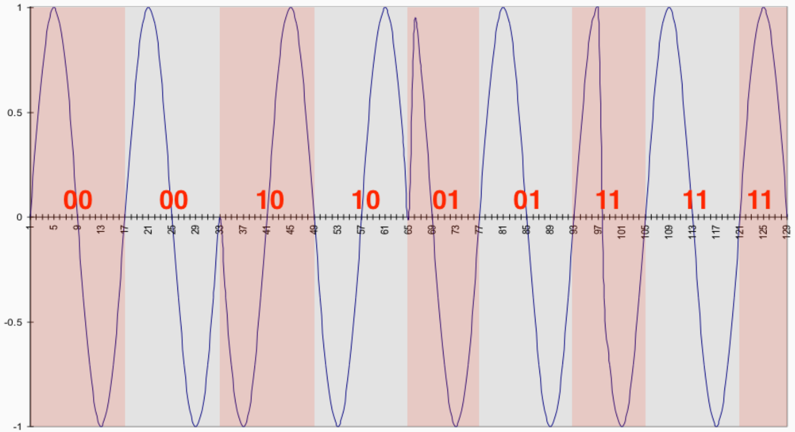
The four signal events can be plotted as a circle, a 'Constellation Diagram':



Warning: there are lots of different kinds of constellation diagrams!

4-PSK

Adding one more degree of freedom means
we can transmit twice as much data



Bit and Baud Rate

- **Bit rate**: the number of bits transmitted per second ($\mathrm{bit\,s^{-1}}$)
- **Baud rate**: the number of signalling events per second (Bd)

- 4-PSK shows the difference between bit rate and baud rate
  - a 1 kHz signal using 4-PSK has:
    - bit rate: $2000\,\mathrm{bit\,s^{-1}} \rightarrow 2\,\mathrm{kbit\,s^{-1}}$
    - baud rate: $1000\,\mathrm{Bd} \rightarrow 1\,\mathrm{kBd}$

- The bit rate *can* be greater than the baud rate if each signalling event delivers more than one bit

Nyquist's Theorem

Ignoring the effects of noise, the maximum channel capacity that can be achieved on a channel with bandwidth B and M possible signalling levels is:

$$\boxed{2 \times B \log_2 M \text{ bit s}^{-1}}$$

(we will come back to this next lecture...)

Logarithms

$$\boxed{\log_a x = b}$$

If $a^b = x$,

then b is the logarithm of x to the base a:

$$2^3 = 8 \rightarrow \log_2 \times 8 = 3$$

$$10^2 = 100 \rightarrow \log_{10} \times 100 = 2$$

Logarithms

$$a^m \times a^n = a^{(m+n)}$$

$$\left.\begin{aligned} a^m &= x \\ a^n &= y \end{aligned}\right\} \quad x \times y = a^{m+n}$$

$$\left.\begin{aligned} m &= \log_a x \\ n &= \log_a y \end{aligned}\right\} \quad \log_a(x \times y) = m + n$$

$$\boxed{\log_a x + \log_a y = \log_a(x \times y)}$$

Logarithms and Division

When dealing with division:

$$\boxed{\log({}^{x}\!/\!{}_{y}) = \log x - \log y}$$

$$\boxed{\log({}^{1}\!/\!{}_{x}) = -\log x}$$

(you can work all of these out in relation to the indices rules)

Logarithms

Some other things to know:

$$\boxed{\log 1 = 0}$$

$$\boxed{\log_a a = 1}$$

(you can work all of these out in relation to the indices rules)

Logarithms

To convert from one base to another use:

$$\boxed{\log_a x = \frac{\log_b x}{\log_b a}}$$

Divide the multiplier (x) by the base (a),
both multiplied by a common log of an alternative base (b)

Logarithms

To convert from one base to another use:

$$\boxed{\log_a x = \log_b x / \log_b a}$$

Since calculators usually have logs to the base 10 (and e), we can always find a logarithm to an arbitrary base by using:

$$\log_a x = \log_{10} x / \log_{10} a$$

$$\text{e.g. } \log_2 10000 = \frac{\log_{10} 10000}{\log_{10} 2} = \frac{4}{\log_{10} 2} = \frac{4}{0.30103} = 13.29$$

The important things to remember:

- DTEs and DCEs
- Modems, modulation, and demodulation:
  - amplitude (ASK), frequency (FSK), phase (PSK, 4-PSK)
  - constellation diagrams
- Understand the difference between bit and baud rate
- Know Nyquist's Theorem and it's implications for channel capacity

Logarithms crib sheet

$$\boxed{\log_a x = b}$$

If $a^b = x$,
then b is the logarithm of x to the base a

Special cases:

$$\log 1 = 0$$

$$\log_a a = 1$$

Useful tricks:

$$\log_a x + \log_a y = \log_a(x \times y)$$

$$\log(x/y) = \log x - \log y$$

$$\log(1/x) = -\log x$$

Next time...

More on Data Transmission...

(Back to) Nyquist, bandwidth, and the PSTN